AD-A152 960 COMBUSTION AND MICRO-EXPLOSION OF WATER/OIL EMULSIONS IN HIGH PRESSURE EN..(U) NORTHWESTERN UNIV EVANSTON IL DEPT OF MECHANICAL ENGINEERING.. C K LAW FEB 85 1/1
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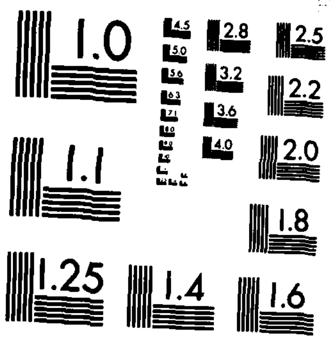

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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ARO 18428.9-EG

FINAL REPORT

"Combustion and Micro-Explosion of Water/Oil Emulsions

in High Pressure Environments"

Grant No. DAAG29-82-K-0023

Submitted to the

U.S. Army Research Office

Research Triangle Park, North Carolina

by

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Statement of Problem

Water/oil emulsions hold potential for soot reduction, multi-fuel capability, and self-extinguishment upon spillage and incendiary ignition. In view of the fact that most of the fundamental research performed so far were in the normal atmosphere although the potential applications of water/oil emulsions are in such high-pressure combustors as diesel engines and gas turbines, this program was initiated to study the combustion characteristics of water/oil emulsions droplets in a high-temperature, high-pressure, convective environment such that useful guidelines can be identified for emulsion formulation and engine design. Of particular interest is the exploration of the phenomenon of micro-explosion which may be responsible for much of the potential benefits of emulsion utilization.

Summary of Accomplishments

During the program period we have accomplished most of our original goals on gaining fundamental understanding of the combustion and micro-explosion properties of water/oil emulsion droplets. We have in addition studied the corresponding problem involving miscible multicomponent droplets. A new reseach project on soot formation in droplet burning has also been initiated. Furthermore, as a result of the present experimental study, we have developed special techniques useful for droplet combustion studies. Notable among them are a droplet generator and a phase-discrimination sampling probe. Highlights of the specific accomplishments are summarized in the following.

1) Combustor Development

A high-pressure (up to 20 atm), high-temperature (up to 1000°K), continuous flow reactor has been developed to study the combustion characteristics of small (about 200 microns), freely-falling, mono-sized fuel droplets generated by the ink-jet printing technique. The droplet generator developed is very versatile and stable, and is ideally suited for the fundamental studies of droplet combustion. When coupled with stroboscopy, we are able to determine the instantaneous droplet size and thereby the droplet burning rate with great accuracy.

2) Development of Phase-Discrimination Sampling Probe

In the study of multicomponent droplet combustion, there is the need to time-resolve the fuel composition both in the gas phase as well as within the droplet. We have designed a phase-discrimination sampling probe based on the inertia separation technique. That is, as the droplet undergoes free fall, a gentle lateral suction is applied which abstracted the gaseous components while allowing the droplet to fall into a liquid sampling probe. Detailed photography and mass balance show that the probe works well.

3) Gasification Mechanisms of Multicomponent Droplets

We have obtained convincing evidence on the gasification mechanisms of multicomponent droplets. Experimental data have been taken on the burning rate and the flame history of freely-falling isolated droplets of one-, two-, and three-component miscible fuel blends, which may also be doped with trace quantities of surfactant normally used as stabilizing agent for water/oil emulsions. As an illustration, the experimental result on two-component fuels show a three-staged combustion behavior, namely an initial period during which the volatile component in the surface layer is preferentially gasified while the droplet temperature is relatively cold; a final, quasi-steady period during which the droplet interior concentration distribution remains constant, the surface region is more concentrated with the less volatile component, and the droplet temperature is relatively high; and a short transition period during which the droplet temperature increases rapidly, the burning rate is extremely low, the flame size shrinks, and the flame temperature diminishes. These results show that even when diffusion is the only liquid-phase transport mechanism, during the initial stage the surface components gasify in a somewhat batch distillation manner because of the thin diffusional layer involved. Thus the overall gasification behavior resembles a mixed mode mechanism intermediate between those of liquid-phase mass-diffusion limited and batch distillation. Theoretical results substantiate these observations and interpretations.

4) Characteristics of Micro-explosion

We have gained substantial understanding on several aspects concerning the micro-explosion mechanisms of multicomponent fuel droplets including those of water/oil emulsions.

First, we have demonstrated experimentally that increasing pressure enhances the occurrence of micro-explosion, hence verifying our previous theoretical predictions. The results show that increasing pressure may induce micro-explosion of a mixture which otherwise does not micro-explode under atmospheric pressure. For mixtures which do micro-explode under atmospheric pressure, increasing pressure will advance the instant of its onset in the droplet lifetime. For example, with 10% water addition in hexadecane, the instant of micro-explosion is advanced from 95% to 15% of the droplet mass lifetime. The practical implication of this finding for application in internal combustion enginers is obvious.

Second, we have found that for mixtures of alkanes and alcohols, the use of an alcohol as the light component can greatly facilitate micro-explosion while the use of an alkane as the light component practically has no effect on micro-explosion. From practical considerations this may be an added advantage of alcohol blending in the formulation of hybrid fuels.

Third, we have observed that the onset of micro-explosion in water/oil emulsion droplets is preceded by the clearing up of the normally milky macroemulsion, indicating the breakdown of the emulsion structure.

Fourth, we have quantified the differences in micro-explosion characteristics between macro- and micro-emulsions; the Army's fire-resistant fuel is a micro-emulsion. Results show that the combustion behavior of micro-emulsions resembles that of miscible fuel mixtures. That is: (a) they micro-explode only towards the end of the droplet lifetime and (b) increasing pressure has no noticeable effct on the characteristics of micro-explosion. However, with macro-emulsions, micro-explosion occurs much earlier in the droplet lifetime while its initiation is also facilitated with increasing system pressure. The differences could be due to the fact that micro-emulsions are more like solutions which generally do not easily micro-explode.

5) Soot Formation and Destruction in Droplet Burning

We have also completed an experimental study of soot formation during the combustion of droplets of pure and multicomponent fuels. The emphasis is on the physical and dynamic factors influencing soot formation and destruction, using time-resolved photography and sampling. Results show that, except for excessively sooty situations, the instantaneous amount of soot present is proportional to the instantaneous flame size, that near-complete oxidation of soot can be achieved by confining it within the regressing, closed flame, and that weak convection promotes soot oxidation while early extinction can lead to substantial soot emission. The effects of blending a sooty component with a non-sooty component of different relative volatility have also been quantified.

List of Publications

1) "An Experimental Investigation on the Gasification Mechanisms of Freely-Falling Multicomponent Droplets," by C. H. Wang, X. Q. Liu, and C. K. Law, Paper No. 82-81, Fall Tech. Meeting of the Western States Section of the Combustion Institute, Livermore, Calif., Oct. 11-12, 1982.

2) "A Preliminary Investigation of Soot Formation from Multicomponent Droplet Combustion," by A. L. Randolph and C. K. Law, Paper No. 83-10, Tech. Meeting of the Central States Section of the Combustion Institute, University of Kentucky, Lexington, KY, March 21-22, 1983.

3) "Heat and Mass Transfer in Combustion: Fundamental Concepts and Analytical Tehniques," Plenary Lecture, ASME-JSME Joint Thermal Engineering Conference, Honolulu, Hawaii, March 20-24, 1983; Conference Proceedings Vol. 2, p. 535-559; also in Progress in Energy and Combustion Science, Vol. 10, pp. 295-318 (1984).

4) "Micro-Explosions of Fuel Droplets under High Pressure," by C. H. Wang and C. K. Law, Paper No. 83-46, Western States Section Meeting of the Combustion Institute, Los Angeles, Calif., Oct. 17-18, 1983.

5) "Soot Formation and Destruction in Droplet Burning," by A. L. Randolph and C. K. Law, Paper No. 84-101, Fall Tech Meeting of the Western States Section of the Combustion Institute, Stanford, Calif., Oct. 22-23, 1984.

6) "Simulation of Fuel Droplet Gasification in SI Engines," by X. Q. Liu, C. H. Wang, and C. K. Law, ASME J. of Engineering for Gas Turbine and Power, Vol. 106, pp. 849-853 (1984).

7) "Combustion and Micro-Explosion of Freely-Falling Multicomponent Droplets," by C. H. Wang, X. Q. Liu, and C. K. Law, Combust. Flame, Vol. 56, pp. 175-187, (1984).

8) "Micro-Explosion of Fuel Droplets under High Pressure," by C H. Wang and C.K. Law, Combust. Flame, Vol. 59, pp. 53-62 (1985).

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Advanced Degrees Awarded

C. H. Wang, Ph.D., 1983

A. L. Randolph, M.S., 1983

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